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Introduction

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Railway timetables and traffic management are inherently linked. In practice, however, the timetable is often only loosely connected to its execution. Customers, drivers, conductors, designers and dispatchers use different sources of information and take decisions based on respectively experience and rules. Whereas railway schedules principally are deterministic, train operations depend on so many internal and external influencing factors that the real arrival and departure times vary to a greater or lesser extent, i.e. they are stochastic. The art of design and construction of railway timetables is to develop a consistent, reliable model of train operations that efficiently supports the designers and railway personnel, matches transport market demands, and is feasible, as well as economical.

Currently, a lot of timetables are still based only on deterministic running times and (minimum) headway times between the trains, rounded to full minutes and represented by simple train diagrams. These may contain hidden conflicts between the train paths, if the applied standard minimum headway times do not match the constraints. These problems may be due to the length of specific signal block sections, local speed restrictions, different deceleration rates or the length of the trains. Thus the minimum headway time between individual pairs of trains may not only be larger than scheduled, but also vary at the same location due to driver behavior or weather impact.

The first and necessary step to guarantee the existence of a conflict-free timetable is the estimation of blocking times. The blocking time is defined as the smallest time interval a train can be given a movement authority for in order to proceed without hinder until the corresponding signal block and track section respectively is cleared. The added value of blocking time graphs is that they represent the use of infrastructure capacity per train at a precision of seconds (!) and easily indicate any conflict in a timetable or actual train schedule by means of a virtual overlap of the blocking times of different trains. Where there is a conflict between the headway

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distances of different trains the signaling and train protection system automatically would force the following train to decelerate in order to assure the safe headway to the preceding train. The latter would lead to a bend of the train path of the hindered train and an increase of its blocking time. Furthermore, the remaining buffer time between the end of the blocking time of the preceding train and the begin of the blocking time of the following train at the critical signal block can be calculated exactly.

A conflict-free timetable is essential for achieving high performance and reliability of train operations. The potential conflict points in a railway network are not limited to stations and platform tracks, but may be located also at merging and crossing points of lines and routes. All need to be integrated in a consistent microscopic infrastructure and a corresponding train operations model containing scheduled train paths and blocking times that guarantee smooth running of trains without unnecessary deceleration when strictly following the schedule.

The application of blocking time theory in railway timetabling and capacity estimation is an outstanding example of feedforward microscopic railway planning. From its first publication by Happel (Happel 1959) it took about 30 years before it became a national design standard in Germany and another 10 years before it became acknowledged internationally by a UIC norm in 2004 (UIC 2004). While its use on double track lines with mono-directional traffic is easy, the estimation of blocking times and of capacity for single track lines is more complicate.

Landex describes in the first article specific issues related to single track lines in Denmark in order to estimate the overall capacity in conformity to the principles of the UIC norm based on division into sections of line and the location of block signals. The virtual 'compression' of blocking time graphs allows evaluation of the impact on capacity consumption of different locations for bi-directional crossing loops along the line. He shows, too, that the UIC norm can be used effectively to assess the performance of different dispatching strategies for maximizing capacity of only one track of double track lines during contingency bi-directional operation, depending on the block signal spacing in the opposite direction.

Another topic of feedforward scheduling with regard to the design of dense train services is discussed by Caimi et al. in the second article. The railway network is decomposed into condensation zones at the main stations, where capacity is limited and trains are scheduled running at maximum speed and regular short intervals, and compensation zones along the links, where recovery time is introduced to increase stability. Maximum train frequency and conflict-free routing are achieved by means of a fixed-point iteration heuristic of the number of discrete time steps needed to run through a railway yard and station, modeled as a conflict graph. The model was been implemented and tested in the railway network of Berne/ Switzerland, and demonstrates its performance by solving the scheduling problem for short time intervals within a small number of seconds of computation time.

The challenge is to develop models that enable estimation of the optimal size of timetable slack for both running time margins and buffer times, and to distribute the margins over the network such that the trains recover quickly from primary delays and reduce knock-on delays as much as possible. The quality of timetables could then be expressed as a function of the scheduled capacity consumption, the distribution of blocking times and margins, and the ability to recover from perturbations.

Although train operations are monitored automatically based on track occupation and release data, the realized running and dwell times, so far, are insufficiently analyzed with regard to the determination of statistically valid distributions. Fine-tuning of the input parameters for timetables is needed, such that the output of models corresponds better with the revealed railway process times. For the estimation of capacity in bottlenecks, especially in complicated yards and at major stations, the probability and propagation of delays between train pairs at route nodes can be modeled based on the variation of the process times of the individual trains approaching (Yuan and Hansen 2007).

A new, exact and non-discriminatory automatic registration tool of knock-on delays of trains is presented by Daamen et al. in the third article. The through and clearing times of trains passing insulation joints generated by standard signaling, safety and train describer systems are recorded in order to model the use of infrastructure capacity and the performance of individual trains by means of a colored Petri net. The time, location and train that caused hinder to other trains, and their knock-on delays are computed automatically on the basis of an analysis of the actual blocking times and speeds of the involved trains. In comparison with the existing incident and delay monitoring tools, the new tool enables a much higher reliability, exactness and objectivity of reporting, whilst the signaller can be relieved of a complicated but routine task and instead focus on conflict solving in case of perturbations.

Automatic registration of primary and knock-on delays enable the development and calibration of more sophisticated on-line delay prediction models and would improve the reliability of dynamic passenger travel information for lines, corridors and larger networks. These could replace the current train delay information used for actual train departure displays, which is based only on earlier recorded rounded-up measurements of the same train without considering the probability of further hindrance or recovery from delay. The broader application and analysis of automatic, dedicated and exact train delay records would allow, too, better insight into the reasons for delay and improve the quality of forecasts regarding the duration of disturbances.

Optimization models are proving their power to generate near-optimal solutions for scheduling problems of trains in heavily occupied complex and large networks. As the computation effort for the resolution of scheduling problems in large railway networks is still costly, the aim is to find intelligent and fast algorithms without significant reduction of solution quality. The ability of optimization models to handle adequately signaling constraints in a network is of prime importance for their acceptance as decision support tools for practical operations.

D'Ariano & Pranzo describe in the fourth article how their advanced dispatching model can achieve minimum delay propagation in a dispatching area in cases of severe disturbances by means of decomposition of a longer time horizon of several hours into tractable intervals, which are solved by alternative graphs in cascade. A range of timetable disturbances is inserted into a given infrastructure network and timetable in the Netherlands in order to test the performance of respectively a Branch and Bound and First Come First Served algorithm, as well as individual and iterative rescheduling strategies through a number of computational experiments.

Headway and route conflicts between the simulated trains runs are detected and solved even before they occur via analysis and updating of blocking time graphs and speed profiles such that the sum of consecutive delays is minimised. The dispatching system proposed can handle one hour instances in the tested dispatching corridor of 50 km length within a few seconds of computation time, while the propagation of medium to larger disturbances in a two hour traffic period is solved to optimality within five minutes. The tool, thus, is considered to be suitable for real-time railway traffic management in single dispatching areas.

The feedback of detailed information on the actual state of use of track capacity, signaling and train headway is a prerequisite for effective rescheduling, dispatching and optimization of train operations. Albrecht introduces in the fifth article a model for anticipating train driving in order to determine the optimal order of trains in perturbed traffic conditions. The performance of driver assistance systems concerning the exactness of the advisory speed and the real time and location of the start of coasting could be improved significantly in order to reduce energy consumption and train delays. As the computation of the optimal arrival times and train speeds at conflict points is time critical and needs nearly continuous updating due to the evolution of the time-space network states, the prediction model for train driving would need to be integrated into the dispatching support tool. Full benefit of such advanced train dispatching would be realized if the trains were operated automatically.

An integrated real-time rescheduling and train driving support system is presented by Luethi et al. in the sixth article. The rescheduling part generates an actual conflict-free schedule for every train that approaches a major station or condensation zone of a network and identifies any delay exceeding a predetermined threshold value, while the new schedule is communicated to the involved trains. A driver-machine-interface in each train (onboard unit) is adapting acceleration/deceleration (cruise control) such that the actual train movement and speed matches with the new slot and the available track capacity is exploited maximally by reducing the buffer times to 15–30 s.

The performance of the rescheduling system is tested and evaluated by means of simulating the impact of varying small original delays for different single trains in the network around Lucerne/Switzerland on the total knock-on delays and the percentage of recovery for respectively a regular and dense timetable. The effectiveness of the integrated real-time rescheduling system depends upon the specific track topology and schedule. The more accurate the design and operation of the individual train paths, the higher would be the benefit of the rescheduling system.

A comprehensive overview of railway design, analysis, dispatching and driver support tools that are applied in Australia is given by Wardrop in the last article. The railway network in Australia is characterized by long distance and regional single track lines used mostly for bulk and intermodal freight haulage on the one hand and suburban double track passenger services around the big cities on the other hand. The areas of analysis consist of route alignment design, train performance and signal system modeling, traffic simulation, driver advice and train pacers.

In a case study of a planned new Great Northwestern Railway freight link, which connects coal fields in northwestern New South Wales with the port via a mountain range, different vertical and horizontal alignment options are investigated in order to compare investment costs, track capacity, rolling stock requirements and operational efficiency. The combined use of proven civil engineering design tools with railway operation modeling and simulation techniques enables developing the most economical solution for the railway infrastructure and future train operations, while assuring feasibility of construction, balance between transport demand and supply, as well as safety and performance of operations.

The papers presented in this Special Issue have been selected as best papers from the 2nd International Seminar on Railway Operations Modelling and Analysis on 28–30 March 2007 in Hannover/Germany and have been reviewed by Board and other members of the International Association of Railway Operations Research (IAROR)[1]. The authors and articles from different universities in Denmark, Germany, The Netherlands, Switzerland, and an Australian railway consultant company represent important contributions to the current state of scientific and professional knowledge in the area of Railway Operations that may stimulate the broader application and further development of models and tools.

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